NOAA Technical Memorandum NWS SR-136

THE PREDICTION OF PULSE-TYPE THUNDERSTORM GUSTS USING VERTICALLY INTEGRATED LIQUID WATER CONTENT (VIL) AND THE CLOUD TOP PENETRATIVE DOWNDRAFT MECHANISM

Stacy R. Stewart
National Weather Service Office
FAA Academy
Oklahoma City, Oklahoma

Scientific Services Division
Southern Region
Fort Worth, Texas
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The Prediction of Pulse-Type Thunderstorm Gusts Using Vertically Integrated Liquid Water Content (VIL) and the Cloud Top Penetrative Downdraft Mechanism

Stacy R. Stewart
Meteorologist (Instructor)
WSO, FAA Academy,
Oklahoma City, OK

ABSTRACT

Operational forecasting of maximum surface wind gusts generated by pulse-type thunderstorms has always been a challenge for meteorologists. Oftentimes it is known that the environment is conducive to the production of strong thunderstorms, but obviously not all of the thunderstorms that develop will generate severe wind gusts at the surface. Through the use of the Cloud Top Penetrative Downdraft Mechanism and the combination of Vertically Integrated Liquid water contents (VIL) and Radar Echo Heights (TOP) obtained from the RADAP II system, a technique has been proposed to assist operational meteorologists in forecasting the gust potential of air-mass (pulse-type) thunderstorms in near real-time situations.

1. Introduction

Observations of cumulus cloud properties by Paluch (1979) indicate that there are little or no horizontal variations across the clouds. This is in sharp contrast to laboratory plumes whose properties conform to a Gaussian distribution. These observations strongly support the Cloud Top Penetrative Downdraft Mechanism first proposed by Squires (1958). He theorized that most of the mixing within convective clouds is due to unsaturated downdrafts initiated near the cloud top and then driven downward within the cloud by negative buoyancy that is generated by evaporative cooling. Penetrative downdrafts are fundamentally distinct from classical dry or moist convection in that they rely on turbulent mixing to provide both the liquid water and dry air necessary for evaporative cooling. Turbulence in clouds is an order of magnitude more severe than in the area surrounding the cloud which means that mixing in clouds is buoyancy driven. This hypothesis better explains Paluch's observations of liquid water content (LWC) "top hat" profiles within large cumulus clouds (abrupt increase in LWC from clear to cloudy air) rather than a Gaussian profile (smooth transition).

Paluch (1979) pointed out that in each case, the observed properties (e.g. mixing ratio) at any level within the clouds were the result of mixing equal parts of cloudy air below the designated level with clear air <u>above</u> the cloud. There was no evidence that air had come from below cloud base, but appeared to have originated near the cloud top. It is important to note that the strongest portion of the updraft in this type of cloud remains undiluted. This implies that penetrative downdrafts do not split the strong updraft, but rather occur around the periphery of the updraft.

Emanuel (1981) took Squires' theory one step further by developing a Similarity Theory for Unsaturated Downdrafts Within Clouds. He proposed that lateral entrainment of atmospheric properties is only important in small cumulus clouds and that dry air entrained near the top of cumulonimbus clouds can generate strong downdrafts that can penetrate to considerable depths within the cloud and occasionally even reach the ground. The one-way nature of the penetrative downdraft process insures that downdrafts resulting purely from the cloud-top instability will be relatively intense and isolated, while any upward return circulation forced by the downdrafts will be broad and weak (Emanuel, 1981). From this research, quantitative downdraft velocities as a function of liquid water content (LWC) can be calculated at various depths within clouds.

2. Penetrative Unsaturated Downdrafts

As previously mentioned, Squires was the first to suggest that penetrative downdrafts are the dominant mixing process in clouds and field research on developing cumuli and large towering cumuli by Telford (1975) and Paluch (1979) provided additional support to Squires' penetrative downdraft theory. Telford's numerical calculations of liquid water content in cumuliform clouds are quite close to observed values.

Most of the entrained air in large towering cumuli was found to have originated several kilometers above the observation level and the mixed regions were typically found in downdrafts and in the weaker updraft regions. This is believed to be a direct result of dry environmental air near the developing cloud top mixing with cloudy air which produces enough evaporative cooling (negative buoyancy) to create downdrafts that descend several kilometers into the cloud. The updraft air is diluted primarily through mixing with nearby downdraft air (Paluch, 1979).

Time-lapsed photography of developing cumulonimbi clearly indicates turbulent motion (eddies) in the upper portion of the cloud which gives thunderstorms that classic "cauliflower" appearance prior to the development of the anvil. The intensity of these turbulent eddies is directly related to the amount of positive buoyant energy being released. The amount of positive buoyancy determines the updraft strength which in turn helps to transport large quantities of LWC to significant heights within the cloud. Between individual turbulent eddies near the cloud top of developing cumulonimbi, unsaturated (dry) air is entrained which evaporates part of the cloud at the edges and produces the "notches" in the "cauliflower tops". If the circulation of the eddies is sufficiently intense, large volumes of dry air can be entrained into the middle or upper portions of the cloud.

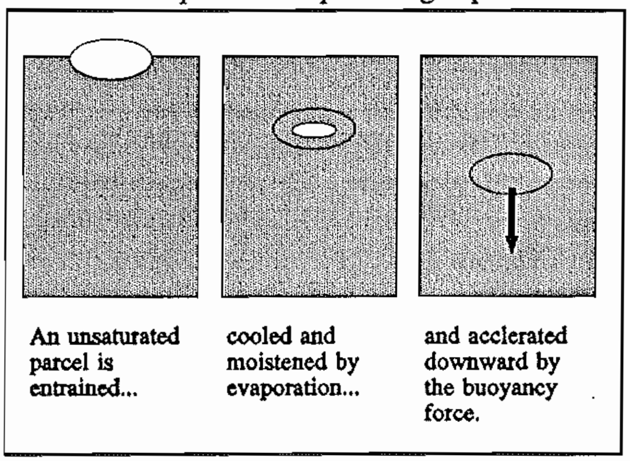

Figure 1. A schematic representation of a dry parcel being entrained at the top of a cloud. The shaded area denotes the cloudy air.

Once inside the cloud, the dry parcel begins to entrain and evaporate liquid water from the cloud and/or precipitation. The evaporation process cools the air parcel which results in the production of negative buoyancy (with respect to the in-cloud lapse rate) and it begins to descend through the cloud (Figure 1). Adiabatic compression acts to warm the air parcel, tending it toward positive buoyancy and a reversal in direction. However, adiabatic warming of the parcel increases the temperature-dewpoint spread which allows for more evaporation and resultant cooling to occur which causes the parcel to become even more negatively buoyant. This process continues until either the evaporation process ceases or the parcel reaches the ground.

Since mixing occurs primarily at the edges of the entrained parcel, the central portion remains relatively dry and, as a result, warms adiabatically which decreases its downward

Corrections to/Clarifications of

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The units of the constants in Equation (2) (page 5) were omitted. Equation (2) is shown below with the appropriate units for the constants (as derived by Emanuel, 1981):

$$W = \left(20.628571\, m s^{-2} \bar{R}_c H \ - \ 3.125 x 10^{-6} s^{-2} H^2\right)^{\frac{1}{2}} \tag{2}$$

Some confusion has arisen over the switching of the units in the second equation on page 6. The step

$$\bar{R}_c = \frac{VIL}{TOP} = \frac{60{,}000\, g m^{-2}}{13{,}720\, m} = 4.373\, g kg^{-1}$$

implies multiplication by the specific volume ($1\ m^3\ kg^{-1}$) of dry air at 700 mb, as is discussed in the preceding paragraph. For clarity, the equation should have been written

$$\bar{R}_c = \frac{VIL}{TOP} = \frac{60{,}000\, g m^{-2}}{13{,}720\, m} \frac{1\, m^3}{kg} = 4.373\, g kg^{-1}$$

Finally, the second-to-last equation on page 6 can be written in a simplified form. Since H and TOP are identical, (3) and (2) can be combined to yield

$$W = \left[(20.628571\, m s^{-2})(VIL) \ - \ (3.125 x 10^{-6} s^{-2})(TOP)^2\right]^{\frac{1}{2}}$$

The author chose the form shown in the Technical Memorandum only to keep with that shown by Emanuel (1981). Either form provides accurate results.

Reference

Emanuel, K.A., 1981: A similarity theory for unsaturated downdrafts within clouds. *J. Atmos. Sci.*, **36**, 2462-2478.

momentum causing that portion to decelerate while the edges continue to rapidly cool and increase in downward momentum which causes that portion of the parcel to accelerate downward. This results in a splitting of the originally entrained volume of dry air into two or more smaller volumes that individually begin the entrainment and evaporative cooling process. This "splitting up" of the original parcel(s) may explain the "gustiness" that is frequently observed in the wind field produced by thunderstorm downdrafts.

Emanuel (1981) noted that occasionally conditions within a cumulonimbus cloud are conducive to the entrained parcel being able to descend all the way to the surface. It is this aspect of the penetrative downdraft mechanism that may help to explain the formation of wet microbursts/downbursts and which also makes it appealing in its use in the near real-time prediction of thunderstorm gusts.

3. Similarity Theory and Its Use in Describing Penetrative Thermals in Pulse-Type Thunderstorms

The dynamics of evaporatively driven penetrative downdrafts are fundamentally distinct from those of moist convective updrafts in that mixing is necessary to sustain the former, while it always works against the latter. Thus, cumulus clouds are relatively broad so as to minimize the effects of lateral entrainment, while the scale of penetrative downdrafts is small enough that entrainment can provide the liquid water necessary to drive the downdraft (Emanuel, 1981).

Doswell (1985) noted that pulse storms are associated with weakly sheared, moderately unstable environments-- i.e. those typifying "air-mass" storm conditions. Emanuel (1981) also stated that the only moist convective motions immune to the influence of penetrative downdrafts are those within clouds whose tops do not meet the cloud-top instability criterion and those associated with quasi-steady convective updrafts which are so intense as to preclude the penetration of downdrafts from aloft (i.e. supercell storms).

Research by Srivastava (1985) concerning evaporatively driven downdrafts in dry microbursts indicated that smaller droplets may evaporate more efficiently, but as a result, the downdraft may become completely saturated and all liquid water exhausted before it reaches the ground. This would result in adiabatic warming causing a reversed sign of direction. However, drop for drop, the larger ones contribute more water vapor by evaporation and the incorporation of large raindrops also enhances water loading of the downdraft which increases the total negative buoyancy. Evaporation of large drops would then replace the negative buoyancy of the water by a negative thermal buoyancy ten times as large! Evaporation of large raindrops would also allow the evaporation process to be spread out over a greater depth. Hence, the evaporation of large raindrops would be the favored mode of generating intense downdrafts (Srivastava, 1985). This is probably due to the larger drops having a greater terminal fall speed and, therefore, can fall a greater distance before collisional or aerodynamic breakup occurs which would then result in an increase of smaller drops that can evaporate more efficiently.

The environment in which "wet" microbursts occur are typical of summer air-mass type thunderstorm development-- a deep, nearly saturated layer with a nearly moist pseudoadiabatic lapse rate that is topped by an elevated dry layer. Caracena, Holle and Doswell (1989) pointed out that the equivalent potential temperature (θ_e) of the dry layer is cold enough and the layer is sufficiently high above the surface that, when it is reduced to its wet bulb temperature by saturation and mixed (in equal parts) with the warm updraft (i.e. high LWC source), there is still enough negatively buoyant potential energy to drive a severe downdraft through the sinking of such a mixed parcel to the surface.

4. Radar Reflectivity and Its Relationship to Rainwater Liquid Water Content

VIL is obtained by calculating the rainwater liquid water content (R_c) at various heights through a series of antenna tilts (volume scans) until the top of the storm is reached. The average R_c between various tilt elevations are then summed up over the depth of the storm and printed out in small pre-determined "bins", each of which covers a 15 nm^2 area [3 nm wide (east-west) and 5 nm long (north-south)]. The RADAP II system not only calculates VIL for each "bin", but also several other radar products-- one of which is radar echo heights (TOP). Equation (1) is used by the RADAP II computer for calculating VIL,

$$VIL = \sum_{i=1}^{n} 3.44x10^{-6}\left(\frac{Z_i + Z_{i+1}}{2}\right)^{\frac{4}{7}} dh \qquad (1)$$

where VIL is vertically integrated liquid water content (Kgm^{-2}), Z_i and Z_{i+1} are radar reflectivity values (mm^{6}m^{-3}) at the lower and upper portions of a sampled layer within a thunderstorm, and dh is the thickness (meters) of the layer of a particular reflectivity in a "bin".

A close look at (1) reveals that VIL is biased towards (a) large radar reflectivity values ($\geq$ 50dBz) and (b) the vertical thickness (depth) of reflectivity. The latter characteristic is the reason for the seasonal differences in VIL values required to produce severe weather. Compared to the summer months, constant pressure surfaces and the tropopause are lower in the winter and spring months due to the much colder temperatures. As a result, the vertical depth of deep convection is usually much greater (therefore, larger VILs can be produced) in the summer than at other times of the year.

High reflectivities are frequently associated with large, water-coated, hailstones which makes large VIL values ($\geq$ 70) good predictors of hail related severe weather events. However, frequently severe wind gusts occur with relatively low VILs ($\leq$ 55-60) and a thunderstorm may go unwarned because the VIL associated with the storm system did not meet a certain VIL threshold for severe weather that day. In the next section, a potential gust technique will be addressed that will hopefully assist warning forecasters by removing some of the uncertainty and guesswork when trying to warn on pulse-type storms.

5. Potential Wind Gust Technique

It is beyond the scope and intent of this paper to include and fully detail all of the equations incorporated in Emanuel's (1981) use of similarity theory for the production of unsaturated penetrative downdrafts. However, calculations of maximum downward vertical velocities (maximum gusts) obtained in the cases in section 6 were made using (2),

$$W = \left(20.628571\overline{R}_c H - 3.125x10^{-6}H^2\right)^{\frac{1}{2}} \quad (2)$$

where W is the maximum downward vertical velocity/surface wind gust (ms^{-1}) obtained by an entrained dry air parcel, $\overline{R}_c$ is the storm-averaged rainwater liquid water content (gg^{-1}) entrained by a parcel, and H is the height (meters) above mean sea-level of the 18 dBz (VIP 1) echo (i.e. the thunderstorm precipitation top). Equation (2) is a combination of mass, momentum, heat, and water deficit equations for penetrative thermals (for a detailed description of [2], the reader should refer to Emanuel, 1981, *J. Atmos. Sci.*, pp. 1547-1548, equation 26).

Caracena and Maier (1987) indicated that an elevated layer of low θ_e air (the likely source of origin of a penetrative thermal) must be present above the deep, moist low-level air to provide sufficient wet-bulb cooling and the generation of negative buoyancy to drive an entrained dry parcel downward. Figure 2 is an upper-air sounding taken at 1500 UTC, 1 July 1975, which was a few hours before a severe wet microburst occurred at the field observing site during the 1975 Florida Area Cumulus Experiment (FACE). The elevated dry layer between 450 mb and 370 mb was the likely source of low θ_e air that produced the penetrative downdraft/microburst as a result of strong evaporative cooling.

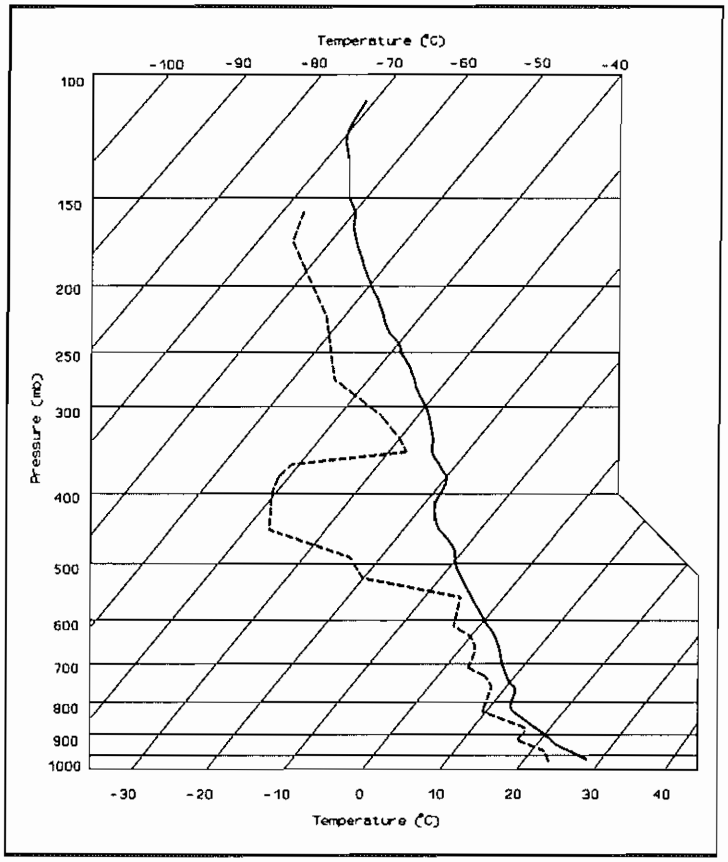

Figure 2. Pre-microburst sounding taken at 1500 UTC, 1 July 1975 during the Florida Area Cmulus Experiment.

Based on their calculations, potential gusts of 20-30 ms^{-1} (38.9-58.3 kt) could have occurred. However, not every thunderstorm that developed that afternoon produced a severe microburst and the 10 ms^{-1} (19.4 kt) range in potential gust velocity is much to broad to be used in a near real-time warning situation. In contrast, the potential gust technique presented here has a mean gust error of ± 1 ms^{-1} (2 kt). Also, in all of the cases which comprise this data set, including those cases presented in section 6, there was sufficient mid-level, low θ_e (dry) air available to be entrained into the thunderstorms.

Large VILs (55-65 Kgm^{-2}) which develop in summertime air-mass convection are likely produced by numerous small (<.75 in.), water-coated hailstones which never descend to the surface due to a very high freezing level. However, the melting of hailstones and any associated water shedding can provide additional large water drops to be evaporated and also produce water loading which would help to increase the negative buoyancy of a wet microburst (penetrative thermal).

In the case studies provided in section 6, VIL and TOP data were used to obtain a storm averaged rainwater liquid water content ($\overline{R}_c$) which is given by (3),

$$\overline{R_c} = \frac{VIL}{TOP} \tag{3}$$

where $\overline{R}_c$ is the storm-averaged rainwater liquid water content (gm^{-3}), VIL is Vertically Integrated Liquid water content (Kgm^{-2} or 10^3 gm^{-2}), and TOP is the 18 dBz (VIP 1) radar echo height (meters). Since $\overline{R}_c$ must have dimensions of gg^{-1} so that it can be used as a dimensionless value in eq. 2, it has been assumed that 1 m^3 of dry air has a specific mass of 1 Kg, which is the approximate density of dry air at 700 mb (mid-levels). This greatly simplifies the calculations and reduces the computer time required to produce a potential gust forecast since the only variables remaining, and which can be easily obtained, are VIL and TOP.

The use of VIL and TOP data along with (2) and (3) to derive the potential downdraft gust of a thunderstorm is illustrated by the following example (the station is assumed to be near sea-level):

A pulse-type thunderstorm has a "bin" that contains a VIL of 60 Kgm^{-2} and a TOP of 45,000 ft (13,720 m) MSL, then

$$\overline{R_c} = \frac{VIL}{TOP} = \frac{60{,}000\,gm^{-2}}{13{,}720\,m} = 4.373\,gkg^{-1} = 0.004373\,gg^{-1}$$

Now using (2),

$$W = \left(20.628571\overline{R_c}H - 3.125x10^{-6}H^2\right)^{\frac{1}{2}}$$

and substituting for $\overline{R}_c$ yields,

$$W = \left[(20.628571)(0.004373)(13{,}720) - (3.125x10^{-6})(13{,}270)^2\right]^{\frac{1}{2}}$$

$$W = 25.48\,ms^{-1} \sim 50.2\,kt$$

It should be pointed out that for a storm containing a VIL of 75 Kgm^{-2} and a TOP of 60,000 ft (18,293m), a maximum gust of 23.34 ms^{-1} (45.9 kt) could occur. That gust calculation is below the severe wind threshold (50 kt), but the 75 VIL is a good indication of hail which probably meets the severe hail criteria (≥ 3/4 in) and the storm should be warned on for that reason. However, the "relatively low" 60 VIL may not gain the attention of a warning forecaster during the summer despite its ability to produce a stronger wind gust. This would also seem to indicate that pulse-type thunderstorms which contain relatively large VIL values (≥ 70) and high TOPs tend to produce severe hail, whereas those storms that have slightly smaller VIL values (≤ 60) and significantly lower TOPs tend to favor the generation of severe wind gusts. Teague (1990) suggested that in summer it takes a storm with much greater vertical extent and a subsequently higher VIL to produce even small hail. Taller storms with large VIL values are an indication of the strength of the updraft which is necessary to support the hailstones above the higher summertime freezing level.

The much lower TOPs and slightly lower VILs associated with those storms that produce severe wind gusts is likely due to an impulsive updraft generated by strong low-level forcing that results in large liquid water contents being carried upward to significant heights. The production of a high concentration of large raindrops within the updraft would reduce its total positive buoyancy due to water loading which in turn would not permit the thunderstorm cell to reach the maximum parcel level (possibly not even the equilibrium level). However, the high concentration of large raindrops would be conducive to accelerating downward an initially "dry" penetrative thermal.

Caracena and Maier (1987) describe the downdraft parcel, which produces a wet-microburst, as a mass of air in free-fall under its own buoyancy force. On impact with the surface, this downdraft parcel develops a maximum surface wind assumed to be equal to the maximum velocity that can be developed in free-fall. In other words, the maximum kinetic energy per unit mass at the surface is equated to the maximum buoyant potential energy per unit mass that is available to the downdraft parcel. This assumption is reasonable since it closely resembles flow against a flat plate observed in laboratory experiments (Batchelor, 1970).

A final potential wind gust is obtained by taking into account the mixing of low-level horizontal momentum. Miller (1967) recommended adding (vectorially) one-third of the mean wind speed in the layer from the surface to 5000 feet to the expected maximum peak gust and this was applied in all of the cases which comprised the data set, including those presented in section 6.

6. Case Studies

In the four case studies provided, RADAP II VIL and TOP data were obtained from WSO Ruskin, FL (TBW), WSMO Old Hickory (Nashville), TN (BNA), and WSO Oklahoma City, OK (OKC). VIL and TOP data for each RADAP "bin" were used directly from the printed data to make calculations of $\bar{R}_c$. However, whenever the RADAP II system printed a specific TOP (with the azran) that was more accurate than the TOP printed in the "bin", the specific radar TOP value was used instead of the "bin" TOP. These cases were selected due to the occurrence of severe wind gusts that were measured by anemometers and/or the extent of wind damage that was reported.

Case 1. 26 Aug 1987, Norman, OK

Synoptic situation-- At 2100 UTC, a quasi-stationary front extended northeast-southwest across Oklahoma from near Joplin, MO southwest to Childress, TX. A weak surface trough had developed south of the front from near Fayetteville, AR southwest to Norman and continuing to near Lawton, OK. Active thunderstorms which had developed earlier that afternoon across southwest Oklahoma were moving northeastward. Ahead of that activity, a well defined north-south oriented outflow boundary had developed and intersected the surface trough about 30 nm southwest of Norman, OK. Temperatures had climbed into the mid-90's with surface dewpoints reaching into the upper-60's to low-70's.

Figures 3 and 4 are the Oklahoma City, OK (OKC) upper-air soundings for 1200 UTC, 26 AUG 1987 and 0000 UTC, 27 AUG 1987, respectively. The mean wind vectors in the lower 5000 feet were 205° at 31 kt and 275° at 09 kt, respectively.

Although the wind speeds in the mid-levels were stronger than a typical summer-time tropical airmass, there was little vertical wind shear and the tropospheric flow was basically unidirectional.

At 2240 UTC, a cluster of thunderstorm cells (Figs. 5a,b) containing VILs of 50-55 Kgm^{-2} and TOPs of 45,000-48,000 ft (13,720-14,634m) was located about 10 nm SSW of the National Severe Storms Laboratory (NSSL) in Norman, OK in "bins" 0/20S, 3E/20S, 0/25S, and 3E/25S. Those VIL and TOP values indicate that potential wind gusts up to 42.0 kt could develop. A time-space conversion reveals that the mean wind vector in the lower 5,000 feet at that time would have been approximately 245° at 18 kt. Adding one-third of the mean wind vector (6 kt) to the predicted gust of 42.0 kt means that the final gust potential would have been 48.0 kt which is just below the minimum severe wind gust threshold of 50 kt. However, the strong outflow from those storms likely enhanced the development of additional convection to the northeast.

By 2251 UTC (Figs. 6a, b), the storm system had moved north-northeast and was centered about 5nm SSW of NSSL. The storms had intensified slightly with VILs of 55-60 Kgm^{-2} while TOPs had decreased slightly to 40,000-45,000 ft (12,195-13,720m). The cells at 3E/15S and 6E/15S would have had gust potentials of 50.3 kt (final gust 56.3 kt) and 48.5 kt (final gust 54.5 kt), respectively.

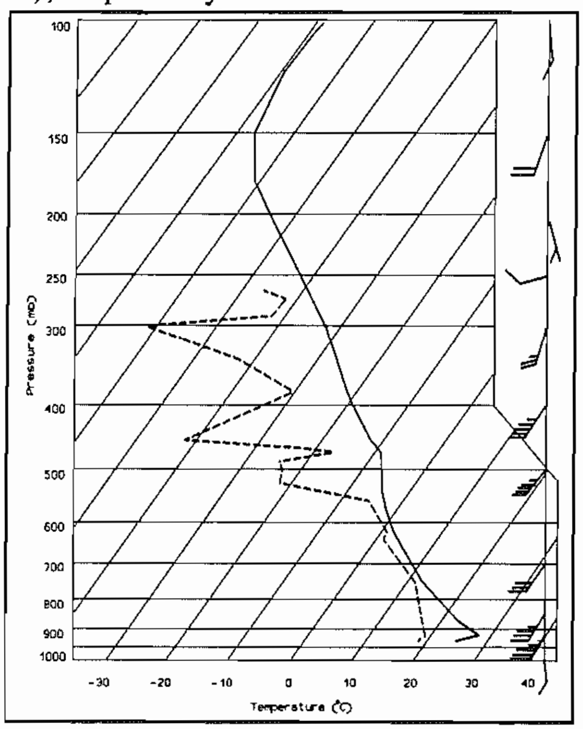

Figure 3. Oklahoma City sounding taken at 1200 UTC, 26 August 1987.

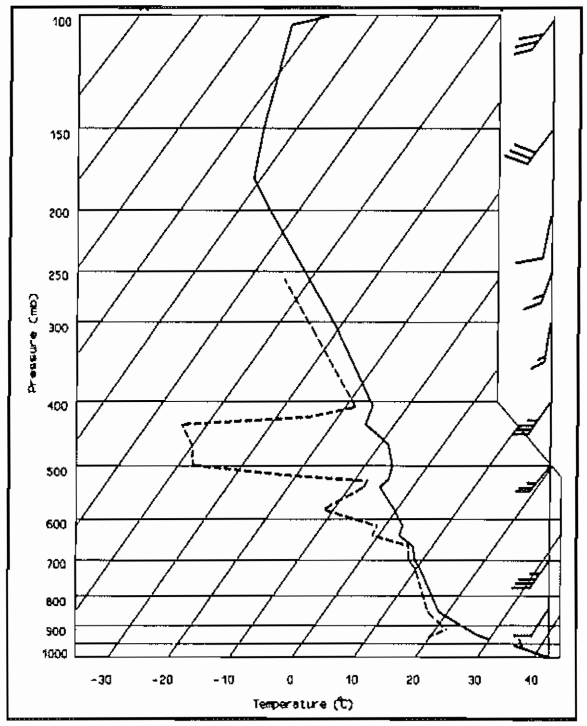

Figure 4. Oklahoma City sounding taken at 0000 UTC, 27 August 1987.

At 2301 UTC, the wind equipment at NSSL recorded a wind gust of 63 mph (54.8 kt) which is very close to the maximum predicted gusts of 56.3 and 54.5 kt calculated from the 2250 UTC VIL/TOP data. It is also noteworthy to point out that the 0000 UTC, 27 AUG 87 OKC sounding (Fig. 4), with the elevated "dry" layer between 530 mb and 430 mb, closely resembles the overall vertical profile of the sounding (Fig. 2) taken prior to the occurrence of the FACE severe microburst that was mentioned by Caracena (1987). This emphasizes the need for an <u>elevated</u> source of low θ_e air to produce wet microbursts in the summer months due to the abundance of moist air in the low-levels. This is in contrast to the environmental ingredients necessary for the production of dry microbursts which requires rain or ice particles to fall through a layer of low θ_e air in the low-levels below the cloud base.

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OKC VIL MAP 2240Z,    AUG 26, 1987

CODE VALUE....  7   8   9   A   B
VIL(KG/M**2).. 35  40  45  50  55



        24  12   0  12  24
      ...W...W...+...E...E..
15N       *             *
10N      *               *
 5N     *                 *
 0+     * 1      *        *
 5S    11 21343    .NSSL  *
10S     14344541 1 121   172
15S   32155666521239931 *155
20S    1346417658A9B8111  1
25S   1 235424542* * *
30S    1 1112211
35S    111  111111     Fig 5a
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OKC  ECHO TOPS MAP 2240Z,  AUG 26, 1987

MAX TOPS. 51000 48000 48000 47000 46000
AZIMUTHS.   184   152   158   256   164
RANGES...    23    20    20    42    23

CODE VALUE......  5   6   7   8   9   A
HEIGHT(1000 FT). 25  30  35  40  45  50

          24  12   0  12  24
        ...W...W...+...E...E..
15N         *             *
10N       6*               *
 5N     565                 *
 0+     555553 32  *        *
 5S     566655555           *
10S     5556576674 657753 5577
15S     5567777777777998435576
20S     4767987998999A97755655
25S     4588987788A98986455554
30S     4447766688655665555444
35S     344445755555555555  4  Fig 5b
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OKC VIL MAP 2251Z,    AUG 26, 1987

CODE VALUE....  8   9   A   B   C
VIL(KG/M**2).. 40  45  50  55  60



        24  12   0  12  24
      ...W...W...+...E...E..
15N       *             *
10N      *               *
 5N     *                 *
 0+     *   1 31 *        *
 5S   7 * 14674    .NSSL 1*1
10S   5411446532352444311446
15S   124423235377BC93 11*
20S     1243223445582  *1
25S   1   1222212* * *  1
30S   1 1    1 112
35S    111    1131     Fig 6a
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OKC  ECHO TOPS MAP 2251Z,  AUG 26, 1987

MAX TOPS. 49000 48000 46000 44000 44000
AZIMUTHS.    90   158   166   178   184
RANGES...    69    20    21    20    20

CODE VALUE......  5   6   7   8   9   A
HEIGHT(1000 FT). 25  30  35  40  45  50

          24  12   0  12  24
        ...W...W...+...E...E..
15N     5   *             *
10N     5555               *
 5N     5455552             *
 0+     645655665  *        *
 5S     855655655     43 4 577
10S     7545667665566777644577
15S     5546776687878999545566
20S     4357876676999999544555
25S     4447787666677565455555
30S     4444465555555556555 4
35S     354444555555 5 555     Fig 6b
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Case 2. 19 Jul 1988, Tampa International Airport, Tampa, FL

Synoptic situation-- At 2000 UTC, thunderstorms continued to develop just inland from the Florida west coast along the seabreeze front. The atmospheric conditions were typical of summer-- abundant low-level moisture and light winds aloft. In the low-levels, mean winds in the lower 5000 ft were from the southeast at 6 kt (sounding not shown).

At 2011 UTC, a small cluster of strong thunderstorms (Figs. 7a, b) was oriented east-west across downtown Tampa, FL and over the Tampa International Airport (TPA) which is located in the extreme eastern portion of "bin" 6W/15N. Four VILs of 55 Kgm^{-2} were indicated with TOPs from 35,000 to 45,000 ft (10,671-13,720m) MSL and two VILs of 45 Kgm^{-2} with TOPs of 25,000 and 30,000 ft (7622m and 9146m) MSL indicated in "bins" 6E/10N and 9E/10N, respectively. Those VIL values aren't spectacular compared to most severe weather standards. However, potential wind gusts of 45.4, 50.3, 50.3, 54.2, 53.1 and 50.2 kt could have occurred in "bins" 6W/15N, 3W/15N, 0/15N, 3E/15N, 6E/10N, and 9E/10N, respectively. Adding one-third of the lower mean winds (2 kt) to those values indicates final potential gusts ranging from 47.4 to 56.2 kt could have occurred over much of the Tampa metropolitan area. The storms were moving to the west and the "bin" (3W/15N) located immediately east of TPA contained a cell that had a final gust potential of 52.2 kt.

At 2025 UTC, a wind gust of 52 kt was recorded at the Tampa International Airport. Once again, the maximum wind gust observed by a nearby anemometer was very close to the final predicted wind gust.

By 2030 UTC (Figs 8a, b), VILs over downtown Tampa (3W/15N and 0/15N) had decreased to a maximum of 50 Kgm^{-2} while TOPs remained nearly steady at 40,000 ft (12,195m). Also, a new cell (9W/20N) containing a VIL of 60 Kgm^{-2} and a TOP of 49,000 ft (14,939m) had developed over northwest Tampa. The storms over downtown Tampa both had final gust potentials of 48.3 kt and the storm over northwest Tampa had a final gust potential of 47.2 kt. It is also important to point out that the TBW RADAP II system was operating on a 20 minute volume scan cycle which means that a significant VIL/potential gust could have been missed during the 19 minute "no-data" period between 2011 and 2030 UTC. However, assuming that the storms over Tampa had remained nearly steady during that time, severe wind gusts would have occurred for a considerable time period over a major metropolitan area which is very significant.

At 2050 UTC (VIL/TOP data not shown), VILs had decreased to 40-45 Kgm^{-2} and TOPs had remained nearly steady with heights between 40000 to 45000 ft (12195-13720m) indicating the storms were collapsing and likely producing strong wind gusts at the surface. In fact, subsequent VIL and TOP maps indicated that was the case.

At 2048 UTC, a report was received at WSO Tampa Bay (TBW) of several Tampa homes being damaged by uprooted trees and falling branches. This damage likely occurred between 2011 and 2030 UTC associated with the cells located at 3E/15N and 6E/10N which had final gust potentials of 56.2 and 55.1 kt.

```
TBW VIL MAP 2011Z,    JUL 19, 1988

CODE VALUE....  7    8    9    A    B
VIL(KG/M**2).. 35   40   45   50   55

        24  12   0  12  24
      ...W...W...+...E...E..
30N       18A94
25N       11 1* * * *
20N      6 *  159641  *
15N      796978BBBB9 1122
10N   265599A87563699644652
 5N   798544421     33267621
 0+   2573 11 1  *   1164531
 5S   6532111              *
10S   212111  1           *
15S   1221*1             *
20S   23211* 1         *  Fig 7a
```

```
TBW  ECHO TOPS MAP 2011Z,  JUL 19, 1988

MAX TOPS. 57000 51000 50000 47000 45000
AZIMUTHS.   160   336   342   104   340
RANGES...    64    39    38    97    19

CODE VALUE......  6   7   8   9   A   B
HEIGHT(1000 FT). 30  35  40  45  50  55

          24  12   0  12  24
        ...W...W...+...E...E..
30N        798997      55
25N        66777* 777* *
20N        6411 5999772 *    7
15N      58887989988787777776
10N     9978989876665567778777
 5N     987898765     56777877
 0+     987785445  *   6777777
 5S     777777775       677777
10S     7777778765643      * 7
15S     767777778775442   *
20S     77677777776544 1* 11    Fig 7b
```

```
TBW VIL MAP 2030Z,    JUL 19, 1988

CODE VALUE....  8    9    A    B    C
VIL(KG/M**2).. 40   45   50   55   60

        24  12   0  12  24
      ...W...W...+...E...E..
30N      11484
25N       2  * * * * *
20N     51 *4AC9321   *
15N     77979BA9AA42  11*
10N   7735877656865321221*
 5N   A83112211     64211 *
 0+   531 11     *  342111*
 5S   3 1 1 1             *
10S      *               *
15S   11  *1 1          *
20S   1    1111       *  Fig 8a
```

```
TBW  ECHO TOPS MAP 2030Z,  JUL 19, 1988

MAX TOPS. 52000 51000 50000 49000 47000
AZIMUTHS.   328   172   178   336   320
RANGES...    22    57    56    21    22

CODE VALUE......  5   6   7   8   9   A
HEIGHT(1000 FT). 25  30  35  40  45  50

          24  12   0  12  24
        ...W...W...+...E...E..
30N      77777886     33
25N      57552 778776* *
20N      664 79AA999972 *   67
15N     7988989A99887773467756
10N     9999988876665567777777
 5N     997778765     56777777
 0+     987777753  *  55777777
 5S     677767644     16777777
10S     6776777766         777
15S     77777777775       *
20S     77677777774     *    7  Fig 8b
```

Case 3. 4 Jun 1990, Vero Beach (VRB)/Indian River County, FL

Synoptic situation-- At 2100 UTC, considerable convective activity was developing over mainly the eastern portion of the Florida peninsula with some stronger deep convection occurring in the vicinity of the seabreeze front. The atmospheric conditions were similar to those of Case 2 except that the winds aloft and in the boundary layer were light southwest to westerly (TBW sounding not shown). The weak low-level westerly winds were converging with the easterly onshore seabreeze to produce good boundary layer forcing just inland from the Florida east coast. The mean winds in the lower 5000 feet were westerly at about 6 kt. It should also be pointed out that the Tampa Bay Area (TBW) RADAP II system was operating on 20 minute volume scan intervals and, as a result, VIL and TOP data were unavailable at 2200 and 2220 UTC.

By 2210 UTC (Figs. 9a, b), a cluster of very strong thunderstorms had developed over the northeast one-fourth of Indian River County along the Florida east coast and contained four VILs of 65 Kgm^{-2} and TOPs from 50000-53000 ft (15244-16159m) with potential gusts ranging from 48.2 to 44.6 kt. Adding one-third of the lower mean winds (2 kt) to those gusts would produce final gust potentials of 46.6, 46.6, 50.2, and 50.2 kt in "bins" 5N/105E, 0/105E, 5N/102E, and 0/102E, respectively.

The northern end of the cluster of thunderstorms passed over Sebastian, FL (located in the northwest corner of "bin" 5N/105E) causing wind damage in the form of downed powerlines at 2220 UTC. The cell immediately west of Sebastian ("bin" 5N/102E) which had a final gust potential of 50.2 kt was the likely storm that produced the damage.

By 2230 UTC (Figs. 10a, b), the northern end of the cluster of storms had weakened, the central portion remained the same, while new convection had developed on the southern end. Peak VILs remained near 65 Kgm^{-2} with TOPs holding between 52,000 to 55,000 ft (15,854 to 16,768m). Peak gust (final gust) potentials of 45.8 (47.8), 44.6 (46.6), 44.0 (46.0), and 31.1 kt (33.1 kt) were indicated in "bins" 5S/105e, 5S/102E, 0/105E, and 5S/108E, respectively.

New convective development along the southern portion of the thunderstorm cluster was likely due to enhanced low-level convergence resulting from the interaction between the seabreeze and a gust front/outflow boundary that was generated by the 2210 UTC activity to the north. As mentioned previously, enhanced low-level forcing (convergence) can result in rapid and significant increases in storm LWC, increasing the potential for microburst development.

At 2237 UTC, a convective wind gust of 50 kt was reported at the Vero Beach Municipal Airport (VRB-- located in the extreme southwest corner of "bin" 0/108E). The cell in "bin" 0/102E at 2210 UTC that had a final gust potential of 50.2 kt was the likely storm that produced the severe wind gust. Also, some small hail up to .75 inch (1.9 cm) diameter was reported 12 miles west-northwest of VRB at 2230 UTC.

In this case, the damage at Sebastian, FL occurred 10 minutes after a severe wind gust was predicted while the severe wind event at VRB occurred 27 minutes after a severe wind gust was predicted. Although the 2220 UTC VIL/TOP data was missing, that cluster of thunderstorms likely maintained final gust potentials of 47 to 50 kt for nearly 20 minutes which is significant for public and aviation interests and also indicates the need for shorter volume scan intervals to avoid missing peak VIL/TOP values and, in turn, peak (final) potential gust values.

```
TBW VIL MAP 2210Z,    JUN 04, 1990

CODE VALUE....  9    A    B    C    D
VIL(KG/M**2).. 45   50   55   60   65



      60  72  84  96 108 120
       E...E...E...E...E...E.
40N      *        *        *
35N       *        *        *
30N       *        *         *
25N        *        *     12
20N         1*      *    11
15N          *    2114221
10N          *    1168752
 5N       112* 11   19DD71
 0+      222221      5DD2
 5S      7652 23     121
10S      746  *      9C1  Fig 9a
```

```
TBW  ECHO TOPS MAP 2210Z,  JUN 04, 1990

MAX TOPS. 55000 53000 52000 51000 51000
AZIMUTHS.    86    52    92    58    98
RANGES...   111   107   106   104   104

CODE VALUE......  6   7   8   9   A   B
HEIGHT(1000 FT). 30  35  40  45  50  55

         60  72  84  96 108 120
          E...E...E...E...E...E.
40N         *        *        *
35N          *44555   *       33
30N          *4455555 *     7 37*
25N          444455     *36777777
20N        1477444555566666677777
15N        147774455556A6677777
10N        177777455555AABBB77
 5N        677777455 55AABBB7
 0+       867777722    6ABB7
 5S       9977444     226AA66
10S      8677122    2226AA66     Fig 9b
```

```
TBW VIL MAP 2230Z,    JUN 04, 1990

CODE VALUE....  9    A    B    C    D
VIL(KG/M**2).. 45   50   55   60   65



      60  72  84  96 108 120
       E...E...E...E...E...E.
40N      *        *        *
35N       *        *        *
30N       *        *         *
25N        *        *        *
20N         1*      *    11*
15N          *    1 *122 151
10N          *      *2264111
 5N           11    *27865
 0+          *      *8D976
 5S      63221*     3CDB2
10S      755323    218952  Fig 10a
```

```
TBW  ECHO TOPS MAP 2230Z,  JUN 04, 1990

MAX TOPS. 55000 53000 52000 51000 51000
AZIMUTHS.    54    90    96    90   104
RANGES...   111   111   107   102    97

CODE VALUE......  6   7   8   9   A   B
HEIGHT(1000 FT). 30  35  40  45  50  55

         60  72  84  96 108 120
          E...E...E...E...E...E.
40N         *     55 26       *
35N          *   55555*       *
30N          *   555556    7737*
25N            *24555556* 677777*
20N             4455555626667 7777
15N             44455555666677777
10N           77885555266667 7777
 5N          347778555  6ABB77777
 0+        667774445    6ABBB7777
 5S        967774442   26ABBBB777
10S        86777742   256ABBB77   Fig 10b
```

Case 4. 18 Jun 1990, Logan County, KY

Synoptic situation-- At 1100 UTC, a cold front extended northeast-southwest across northern and central Kentucky and western Tennessee in advance of a moderate shortwave trough in the mid- and upper-levels of the atmosphere. Mean winds in the lower 5000 ft. were approximately 260° at 21 kt (BNA & PAH soundings not shown). A band of thunderstorms had developed along the front and a severe thunderstorm watch was in effect for much of central Kentucky. However, no significant severe weather had developed or been reported as the activity moved across south central Kentucky. The highest thunderstorm TOPs associated with the band of convection were reported over far West Tennessee and the highest VILs associated with those TOPs were in the 40-50 Kgm^{-2} range. By 1140 UTC, a small cluster of 50 VILs (VIL/TOP maps not shown) had developed over extreme western Logan County, KY moving east-southeastward.

At 1150 UTC (Figs. 11a, b), 4 "bins" containing VILs ranging from 50 Kgm^{-2} to 65 Kgm^{-2} were located over central Logan County with TOPs ranging from 45,000 to 47,000 ft. (13,720 to 14,329m) MSL corresponding to gust potentials ranging from 40.9 to 51.4 kt. Adding one-third of the lower mean winds (7.0 kt) indicates final gust potentials of 58.4, 56.6, 47.9, and 47.9 kt could have occurred in "bins" 15W/50N, 15W/45N, 12W/50N, and 12W/45N, respectively.

By 1200 UTC (Figs. 12a, b), the maximum VIL coverage had decreased with only one peak VIL of 55 Kgm^{-2} with a TOP near 45,000 ft (13,720m) remaining in "bin" 12W/45N. However, that storm still had a gust (final) potential of 45.5 kt (52.5 kt) despite its apparent weakening. Subsequent VIL/TOP maps indicated the Logan County storm only "pulsed" once before collapsing at 1200 UTC.

Although this storm did not pass near a recording anemometer, reports from the Logan County civil defense and the electric utility company that services that area indicated that damage ranged from numerous large trees blown down across powerlines which caused widespread residential power outages to one barn being completely destroyed. Those damage reports are significant given the relatively sparse population across mostly open farmland in southern Kentucky and were likely caused by a large macroburst.

```
BNA VIL MAP 1150Z,    JUN 18, 1990

CODE VALUE....  9    A    B    C    D
VIL(KG/M**2).. 45   50   55   60   65

        24  12   0  12  24
      ...W...W...+...E...E..
50N   121415DA843* * *
45N   33*  8CA71         *
40N   *   2                *
35N       2
30N                      1
25N          * * * * 2141442
20N        *          *43346
15N       *        11   2218
10N      *         11    *22
 5N     *                 *3
 0+     *        *        * Fig 11a
```

```
BNA  ECHO TOPS MAP 1150Z,  JUN 18, 1990

MAX TOPS. 57000 47000 47000 43000 41000
AZIMUTHS.   276   342   350   284   202
RANGES...   113    52    52    88    21

CODE VALUE......  6    7    8    9    A    B
HEIGHT(1000 FT). 30   35   40   45   50   55

          24  12   0  12  24
        ...W...W...+...E...E..
50N     5565599999777* *
45N     55335999997        *
40N     *  444666         22 *
35N        444         334
30N                    2 35556
25N            * * * *15574677
20N          *         3475667
15N         *        551115446
10N        *         44 1 1*46
 5N       *     1           45
 0+       *        *        43   Fig 11b
```

```
BNA VIL MAP 1200Z,    JUN 18, 1990

CODE VALUE....  7    8    9    A    B
VIL(KG/M**2).. 35   40   45   50   55

        24  12   0  12  24
      ...W...W...+...E...E..
50N     2421346451* * *
45N    374115B83 2       *
40N   *  321256            *
35N       2
30N
25N          * * * * 3312122
20N        *          4*5343
15N       *        111  3433
10N      *         32    * 3
 5N     *                 *3
 0+     *        *        *2 Fig 12a
```

```
BNA  ECHO TOPS MAP 1200Z,  JUN 18, 1990

MAX TOPS. 58000 49000 48000 45000 44000
AZIMUTHS.   272   204   328   346   352
RANGES...   115    25    53    50    49

CODE VALUE......  7    8    9    A    B    C
HEIGHT(1000 FT). 35   40   45   50   55   60

          24  12   0  12  24
        ...W...W...+...E...E..
50N      15557799977777*
45N     37A555999987777    *
40N     * 574468888          *
35N         44455      2322
30N                     332344
25N            * * * * 5547779
20N          *       3 3545769
15N         *        444335776
10N        *      1  554  1* 4
 5N       *     1           34
 0+       *        *        34   Fig 12b
```

7. Discussion

A total of 143 separate cases (including the 4 cases presented in this paper) have been examined for the months of June-September during 1986-1990 from the TBW, BNA, and OKC radar sites. The potential gust technique presented in this paper was used in each case and 82% of the cases verified by reported wind damage and/or severe wind gusts (measured or estimated).

Concerning those cases that did not verify, potential severe wind gusts were predicted, but no severe report was received. However, no cases were observed in which severe wind gusts/damage occurred and the gust potential technique failed to predict a severe wind gust. The most likely reason for lack of verification of a predicted severe wind event is due to the geographical location of occurrence. Most of Oklahoma and Tennessee is rural farmland and much of south Florida is comprised of the Everglades and swampland. Also, most damage reports are the result of downed trees-- a rather scarce commodity across the western half of Oklahoma. As a result, some severe wind events likely occurred but went unreported.

No forecast scheme is better than its verification program. Most of the severe weather reports received at the Norman WSFO are the result of hail occurrences since hailsize is more easily obtained than wind gusts. In those geographical areas where trees are in greater abundance, contacting the 24-hour dispatcher at the utility company that provides electrical power to a county or city can prove to be a valuable source of severe wind reports usually in the form of downed trees or powerlines. This is primarily due to the fact that most customers report power outages to their electric utility company rather than law enforcement agencies.

Table 1 is a sample of potential wind gusts (knots) that could be achieved by using various VIL (Kgm^{-2}) and TOP (100's feet) values. The mean wind speed in the lower 5000 feet would have to be added to these values to obtain the final potential wind gust for a pulse-type storm. The reader is reminded that this technique is not intended for strongly sheared storms, although it occasionally works for short-lived pulse-type storms that develop in a sheared environment. Also, potential gust values were not calculated for VILs ≥75 Kgm^{-2} due to the strong bias of large reflectivity values produced by large, water coated hailstones which creates unrealistic rainwater liquid water contents.

TOP	250	300	350	400	450	500	550	600	650	700
VIL										
40	49.3	46.1	42.1	36.9	29.9	19.4				
45	53.1	50.2	46.5	41.8	35.9	27.7	13.8			
50	56.7	53.9	50.5	46.3	40.9	34.0	24.1			
55	60.0	57.4	54.3	50.3	45.5	39.3	31.1	18.4		
60	63.2	60.7	57.7	54.1	49.6	44.0	36.9	27.0	6.5	
65	66.2	63.9	61.0	57.5	53.3	48.2	41.8	33.4	20.8	
70	69.1	66.9	64.1	60.8	56.9	52.1	46.2	38.8	28.7	9.0

Table 1. Potential wind gust calculations using VIL and TOP data.

In 8% of the cases that comprise the data set for this study (not shown in this paper), observed wind gusts exceeded final predicted severe wind gusts by as much as 7-10 kt. This was likely the result of the development of a "ring vortex" or "rotor microburst/macroburst" (Fujita, 1985). As the horizontal ring vortex expands laterally, friction results in a stretching of the vortex tube/vorticity field, which in turn results in an acceleration of the wind beneath the ring vortex, thereby increasing the peak wind gust. This was noted to occur with storms that had two or more "bins" containing large maximum VIL values (≥65 Kgm^{-2}) which were surrounded by several slightly lower VILs (50-60 Kgm^{-2}). This would tend to support the development of a wider downdraft and a macroburst which, in turn, would likely result in the development of an expanding ring vortex.

Other possible errors in the gust prediction could result from:

(a) **Friction**-- friction was ignored in all gust computations. Obviously in the real world, friction is very much an important factor to be considered since it would tend to reduce the actual wind gust below what would be predicted.

(b) **Data Averaging**-- printed VIL and TOP data were used in all gust computations unless a specific TOP and associated azran was printed across the upper portion of the TOP map. The displayed (printed or on a CRT monitor) alpha-numeric coded VIL and TOP values span a range of ± 2 Kgm^{-2} and ± 2000 ft (610m), respectively. Using the data in this format can result in the overestimation/underestimation of a peak gust. For example, if a "bin" contains a coded VIL value of "B" (55 Kgm^{-2}) and a TOP value of "8" (40,000 ft/12,195m), a potential gust of 51.0 kt is possible. However, since the coded VIL value covers a range of 53-57 Kgm^{-2} and the TOP value covers a range of 38,000-42,000 ft (11,585-12,805m), the gust potential would range from 47.4 kt (non-severe) to 54.1 kt (severe).

(c) **Standard Tropical Atmosphere**-- typical vertical profiles of the thermodynamic variables associated with a standard tropical atmosphere were used in all potential gust computations. In a real-time situation, the sounding close to the time of the event should be used and continuously updated as atmospheric conditions change. For example, the morning sounding may not indicate enough dry air in the mid-levels of the atmosphere to sufficiently drive a severe downdraft. However, satellite and/or synoptic data could indicate an intrusion of dry air in the mid-levels that would then support the production of severe wet microbursts/macrobursts by the time convection develops.

(d) **Vertical Truncation**-- due to the 22° elevation limit, storms very close to the radar (11-15 nm) may have TOP and VIL data truncated, especially if the storms are very tall (≥45,000 ft/13,720m). This would result in considerably lower TOP values, but only slightly lower VIL values which would produce potential gusts higher than expected. However, once NEXRAD is fully installed, overlapping radar coverage should eliminate this problem.

(e) **No Elevated Dry Layer**-- the absence of a layer of "dry" air in the mid-levels of the atmosphere would inhibit the necessary evaporative cooling needed to produce enough negative buoyancy to drive a severe penetrative thermal. However, severe hail could still occur in association with large VIL values that develop in a very moist or nearly saturated environment.

8. Conclusions

The case studies and arguments presented in this paper strongly suggest that the cloud top penetrative downdraft mechanism may be the primary factor behind the production of severe wind gusts/wet microbursts resulting from an intense, impulsive updraft generated by strong boundary layer forcing.

Wet microbursts were observed in three distinctly <u>different</u> <u>geographical</u> locations within the southern/southeastern United States at various hours of the day which would suggest that strong downdrafts generated by pulse-type thunderstorms are <u>not</u> limited to any geographical area or time of day. To produce a severe wind gust at the surface, the presence of an elevated layer of low θ_e air (generally dewpoint depressions ≥20°), based in the mid-levels of the atmosphere (approximately 500mb level and above), is necessary to develop sufficient negative buoyancy due to evaporative cooling. If the conditions are right, a wet microburst emanating from a pulse-type thunderstorm can occur <u>anywhere</u> and at <u>anytime</u>.

A relatively simple short-term, non-statistical, quantitative forecast technique has been presented which is only dependent upon two variables-- Vertically Integrated Liquid Water

Content (VIL) and Radar Echo Heights (TOP). Warning lead times up to 20 minutes prior to the occurrence of a severe wind event are common when using this technique. Not only does the potential gust technique provide a quantitative value concerning wind gusts, but it can also serve as a discriminator between thunderstorms that are more likely to produce hail than damaging winds.

As a result of NEXRAD's increased temporal and spatial resolution over that of the WSR-57/RADAP II system, peak VIL values and better height values of reflectivity and storm echo tops could be easily obtained and incorporated in a computer program that would produce potential gust fields similar to the one that was written for this paper. Figure 13a is a sample field of experimental potential gusts ≥40 kt along with specific peak gust values (the associated azrans are printed across the top of the map) for the TBW radar site at 2011 UTC, 19 July 1988. When compared with the VIL map (Fig. 13b-- same figure as figure 7a in Case 2) for the same time, non-significant cells and a lot of unnecessary "clutter" have been eliminated. Any minimum gust threshold could be programmed by the warning forecaster and, when used along side the VIL field, would assist the warning forecaster in separating the non-severe storms from those that are severe. Although the mean wind vector in the lower 5000 feet of the atmosphere would have to be added to the potential gusts depicted in Figure 13a to come up with the final potential gust, this could easily be incorporated into the same computer program to produce a field of <u>final</u> potential gusts. The mean wind vector would only have to be updated as the warning forecaster deemed it necessary.

```
TBW PEAK GUST MAP  2011Z,  JUL 19, 1988
EXPERIMENTAL POTENTIAL GUSTS    (≥40 KT)
MAX GUSTS(KT)... 54.3  53.1  50.3  50.2
AZIMUTHS........   12    30   360    40
RANGES..........   17    13    15    16

CODE VALUE......   8   9    A    B    C
GUST SPEED(KT)..  40  45   50   55   60

        24  12   0  12  24
      ...W...W...+...E...E..
30N         8
25N          * * * * *
20N        *           *
15N       *    9AAB8    *
10N      * 88      BA    *
 5N     88                *
 0+      *        *       *
 5S      *                *
10S       *              *
15S        *            *
20S         *          *  Fig 13a
```

```
TBW VIL MAP 2011Z,    JUL 19, 1988

CODE VALUE....  7   8   9   A   
VIL(KG/M**2).. 35  40  45  50  5

          24  12   0  12  24
        ...W...W...+...E...E..
30N         18A94
25N         11 1* * * *
20N        6 *  159641  *
15N        796978BBBB9 1122
10N     265599A87563699644652
 5N     798544421     33267621
 0+     2573 11 1  *   1164531
 5S     6532111             *
10S     212111  1          *
15S     1221*1            *
20S     23211* 1        * Fig 13b
```

Output obtained by this technique could also be used as a predictor in the current Severe Weather Probability (SWP) algorithm. This would improve the SWP's capability to denote severe storms due to the <u>non-geographic</u> dependence of the prediction of wet microbursts associated with pulse-type thunderstorms. The NEXRAD storm structure algorithm would determine whether a suspect thunderstorm has a nearly vertical (pulse-type storm) or tilted updraft. In the case of a tilted updraft, the gust potential would not be used or simply carry a smaller weight in the SWP algorithm.

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